A robust spike noise correction method for fMRI

S. Chavez[1], F. Tam[1,2], and S. Graham[1,2]
[1]Sunnybrook Health Sciences Centre, Toronto, ON, Canada, [2]Rotman Research Institute, Toronto, ON, Canada

Introduction

A transient artifactual increase in the k-space MR signal is commonly referred to as spike noise. This artifact is often seen in functional magnetic resonance imaging (fMRI) due to high demands placed on gradient hardware by fast imaging. However, spike noise is a sporadic event that can appear randomly in time and k-space and it is notoriously difficult to trouble-shoot. Furthermore, fMRI relies on subtle time-dependent signal changes and it is particularly sensitive to the effects of noise.

The present work focuses on an existing spike noise detection and correction method, first developed for diffusion tensor imaging (DTI) [1], and adapts it for fMRI purposes. The existing method relies on the sporadic nature of spike noise and the fact that DTI data sets contain redundancy because the same slice is repeatedly acquired (sensitized to different gradient directions) with only slight changes expected between acquisitions. The artifact-free acquisitions are used to help guide the correction. In fMRI, a similar situation exists because the same slice is acquired repeatedly to extract subtle hemodynamic signal changes. Uncorrupted fMRI acquisitions at a given slice can be used to guide the correction of those corrupted by spike noise.

Theory

The existing DTI-specific spike noise correction method was developed for magnitude images. The spike noise signature derived from magnitude images is blurred and affected by Hermitian symmetry. However, for fMRI, raw complex k-space data are more likely to be available. This is advantageous because the spike noise signature is expected to be of higher intensity and more localized in true k-space, thus aiding spike localization. Correction is independent of k-space trajectory. Specifically, if the fMRI scans are acquired with a spiral k-space trajectory, the method can be adapted to the raw one-dimensional (1-D) sampled signal before a gridding procedure interpolates the 1-D signal into Cartesian 2-D k-space.

Other spike noise correction methods have been applied to fMRI [2,3]. However, each of these methods incorporates only a single dimension of information: either spatial information, where the data are processed image by image, or temporal information, where the data are processed pixel by pixel, along all time points. The method presented here is more robust and comprehensive, relying on both the spatial and temporal content of fMRI data.

Methods

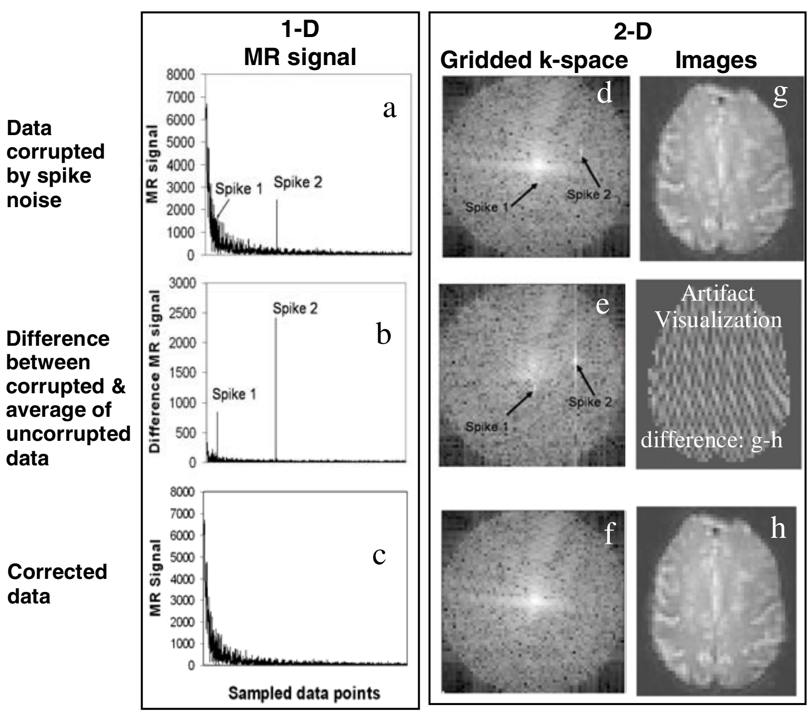
The spike noise correction method consists of three steps:

i) *Spike detection (classification of images)*. An elevated noise floor is expected for magnitude images corrupted by spike noise [1]. Based on a measure of deviation from the median noise floor, a threshold is set to classify corrupted and uncorrupted images. For fMRI, the thresholding procedure can be performed based on the noise floor determined on all magnitude images, at a given slice, for all time points. Due to the large number of time points, all steps can be applied slice by slice. Steps ii) and iii) are applied in k-space and rely on this classification of time points.

ii) *Spike localization*. Based on step i), the average complex k-space of the uncorrupted images is subtracted from each individual k-space yielding difference-k-spaces (dk-spaces) that emphasize the temporal signal changes as well as the spike noise signature. Final localization is obtained through an $N\times N$ sliding window filter that compares the corrupted and uncorrupted dk-spaces, identifying all values out of the expected range given by the uncorrupted data. Removal of the average uncorrupted k-space incorporates the temporal information whereas the sliding window comparisons incorporate the spatial information. The use of complex k-space in these steps increases the sensitivity of the localization, in particular for spike noise affecting regions of high signal (central k-space) where thresholding techniques may fail.

iii) *Spike correction.* All k-space values associated with spike noise are replaced by the average uncorrupted k-space values. An inverse Fourier transform (FT^{-1}) yields the corrected, complex fMRI images.

If the fMRI data are acquired using a spiral k-space trajectory [4], steps ii) and iii) should be performed on the raw 1-D signal before gridding. Gridding causes the spike noise signature to spread and affect more k-space pixels (see streak in e below). In such cases, all 2-D procedures in ii) and iii) are performed along 1-D: the sliding window has the form [-N, +N] and the sampled data points are corrected along 1-D before gridding.



Results

This methodology was tested on an fMRI data set severely contaminated by spike noise. A representative case is shown. The fMRI data were obtained using a spiral out acquisition, hence it was of interest to investigate applying the spike noise correction method, with N=5, to the raw 1-D signal with 5322 sampling points (1st column) and to the gridded 64×64 2-D k-space (2nd &3rd columns) for comparison. As expected, the former reduced the number of data points requiring correction in all cases, improving the accuracy of the result. For the case shown, only 0.17% of the 1-D raw data points were found to be corrupted by spike noise (a) whereas that number increased to 0.71% for the corresponding 2-D k-space (d). The correction is robust in both cases (c and h).

Conclusion

Adapting the DTI-specific spike noise correction method to fMRI was simple and effective. In fact, the method may be more effective and robust on fMRI data due to the larger data redundancy (large number of time points) and the availability of true k-space data. Furthermore, for spiral fMRI acquisitions, the spreading of the spike noise signature in the gridded 2-D k-space can potentially increase the noise floor of the magnitude images, aiding in step i). The robustness and uniqueness of the method lies in the fact that both spatial and temporal information are exploited. Analysis is underway to assess the improvements in fMRI results obtained from this spike noise correction method.

References

[1] Chavez, S. et al. (2006). 14th ISMRM, 1069
[2] Zhang, X. et al. (2001). 9th ISMRM
[3] Zhang, X. et al. (2001). MRI, 19:1037-1041.
[4] Glover, G.H. & Lai, S. (1998). MRM, 39:361-368.